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NUMERICAL ANALYSIS OF INTRICATE ALUMINIUM TUBE AL6061T4 THICKNESS VARIATION AT DIFFERENT FRICTION COEFFICIENT AND INTERNAL PRESSURES DURING BENDING

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ABSTRACT

The Present paper represents the delicate bending process of a 11mm diameter uniform aluminium tube using a series of high internal pressure used inside the die cavity. variable coefficient of friction between the die cavity and tube samples also taken into consideration. The less diameter tube bending is performed inside the die cavity. The tube is pressed inside the die cavity with varying high internal pressure. Since normal bending is not possible for aluminium tubes having a diameter less than 10mm. Also, tube diameter is not uniform and keeps reducing continuously. The large inner diameter of tube is 11 mm at one end and 1mm at another end. The thickness of the tube is 2.5mm. Bending of the tube depends on various parameters such as material property, stresses in the bend, tube wall thickness variation, tube shrinking, neutral axis deviation, internal pressure produced inside die cavity to pressed the materials, coefficient of frction, die rigidity etc. Initially, the simulation is carried out on DEFORM 3D software but due to the limitation of the software solver to take almost a month to get the results and is also not desirable, the ABAQUS software is used later. Results output getting from this software is quite satisfactory. The Thickness variation graphs are plotted against 5 different internal pressures of 0.5MPa, 1MPa, 3MPa, 5MPa and 10MPa. The Thickness variation graph was also plotted against three different friction coefficients of 0.01, 0.001 and 0.005.

KEYWORDS: Internal Pressure, Die Cavity, Tube Shrinking, Rigidity, Friction Coefficient

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Original Article

INTRODUCTION

As we all know that some ovality occurred on round tube bending (ratio of deviation in outer diameter to initial outer diameter) of the tube cross-section. It is difficult to obtain the perfectly round cross section after bending of less diameter cross section tube. Either there is some ovality or damage in cross section due to buckling of tube wall during normal bending technique occurs. It is then essential for industrial applications to acquire a detailed knowledge of the bending reaction of round tubes.

Prior Analyst Shaw and Kyriakides planned as well as developed a bending machine for tubes and performed numerous arrangements on both exploratory and hypothetical to validate. Kyriakides et. al. [2] afterward dissected tube inelastic nature along with bending conjointly examined tube to steadiness conditions beneath bending. Corona et. al. [3] explored tubes steadiness on both application of bending and applied pressure; also [4] examined the tube buckling and degradation on the application of both static pressure and bending. Corona et. al. [5] considered the failure, decadence of long tube, and thin seamless square cross section steel tube reaction subjected to bending, and afterwards also explored [6] the elastic, as well as plastic downgrade and decadence of

steel tubes having cyclic bending, contains square cross-section. Corona et. al. [7] moreover considered the non-uniform decadence of pipes under both static pressure and bending. Corona and Lee [8] performed a series of practicals on bending of alloys of aluminum tubes in order to understand the anisotropy effects of yielding. Kyriakides and Corona [9] later on validated the ratio of diameter upon thickness (Do/t ratio) of such steel tubes which bends plastically. Limam and Corona [10] considered the bending in elastically tube and decadence when bending and internal pressures are predominated. Afterwards, Limam and Lee [11] explored the decadence of tubes of dented impressions under the impact of both bending and internal pressure. The localization in NiTi tubes subjected to internal pressures were investigated by Bechle and Kyriakides [12].

Furthermore, others researchers have submitted numerous analyses in various journals and papers. Tests were conducted tentatively by Elchalakani and Zhao [13] on distinctive Do/t fractions of steel tubes C350 grade beneath immaculate bending. Later they suggested two theoretical as well as simulation models. Jiao et. al [14] tried the behaviour during bending of exceptionally better quality round tubes made up of steel and designed a slimness limit in plastic zone. The various parameters on buckling and after buckling of elastically, thin-walled round and long pressurized tubes were examined by Houliara and Karamanos [15]. Elchalakani et al. [16] investigated the cold-formed CHS impacts on various cyclic, amplitude and bending tests in order to find the fully ductile section slimness limits. Mathon and Liman [17] tentatively considered the decadence of lean, round and hollow shells that were subjected to pure bending and internal pressure. Elchalakani and Zhao [18] explored the roundness of steels tubes having cold formed and concrete-filled which were subjected to different amplitude, bending and cyclic. Fatemi and Kenny [19] suggested about various factors that affect buckling as well as later buckling behaviour of high yield pipelines during bends. Yazdani et. al [20] investigated the failure due to fatigue of tubes having very less wall thickness subjected to bending along with static pressure conditions. Jiang and Chen [21] developed a model also tested with concrete filled thin-walled steel tubes which is parallelly subjected to bending. Shariati and Kolasangiani [22] exploratory examined the 316 grade stainless steel cantilever round hollow tube during bending.

Pan and Wang [23] planned and established a new measuring device in 1998. It is equipped with sinosoidal bending device which examines numerous forms of tubes subjected to bending. The moment, Pan et. al [24] examined stability and reaction of stainless steel shell of 304 grades under bending with various parameters, Lee and Pan [25] investigated the impact of the diameter to thickness ratio on the stability and reaction of round tubes on bending. Lee and Pan again [26] investigated the impact of curve bending-rate and diameter to thickness ratio on the reaction as well as the rigidity of round shell placed under cyclic bending. Chang and Pan [27] tested the buckling failure life calculation of round tubes placed under bending.

Under viable mechanical applications, tubes are exposed in adverse conditions, so that material on such conditions might erode the tube surface and produce irregularities. Also, As employing a shell, it should have a proper plan. Mechanical and Buckling failure behaviour for irregular shell surfaces differs from plain surface tubes. Lee and Hung [28] considered varieties in irregularity which happened in round shell placed under bending conditions. Later Lee considered the different failure behaviour that arise due to buckling of irregularity in round shell subjected to bending. Lee and Hsu [30] tentatively examined the visco-plastic reaction of the irregular round shell under bending.

NUMERICAL ANALYSIS ON INTRICATE ALUMINIUM TUBE BENDING

Here, a study of the effect of internal pressure and friction on the wall thickness variation has been carried out for tube

bending. Figure shows the required tube shape for this case. It is a tube having two right angled bends. The thickness is uniform and is equal to 2.5mm.

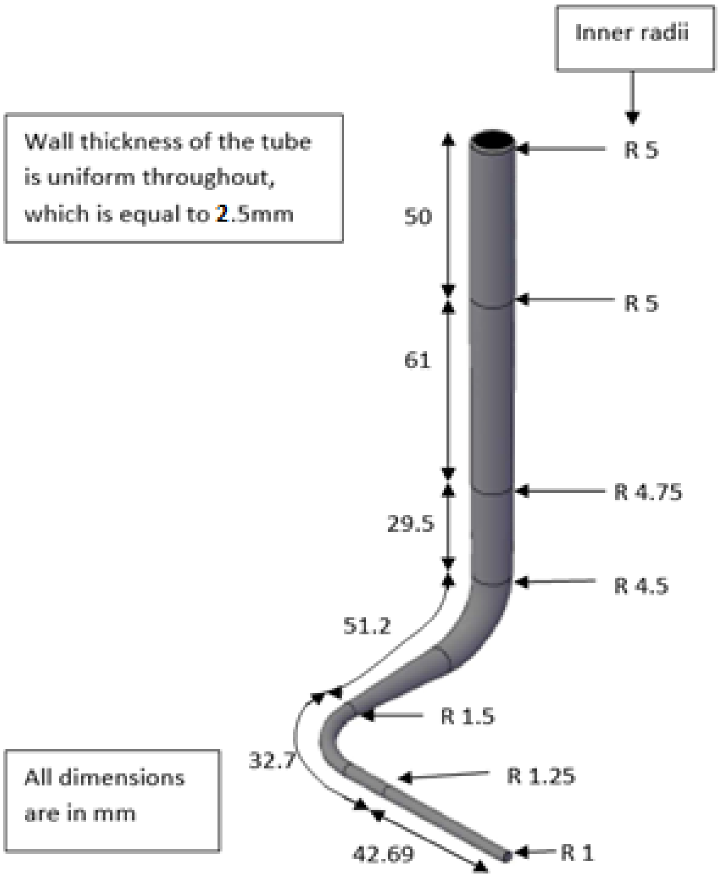


Figure 1 : Required Tube Shape for Tube Bending

Aluminium alloy is used as the material of the tube. The properties of Aluminium alloy Al6061T4 are given in the table. The die cavity is made in the shape of the required formed tube. The initial tube is of cylindrical shape having an outer diameter equal to 11mm and thickness equal to 0.5mm. The initial length of the tube is taken as 300mm. A punch is used to push the tube into the cavity while internal pressure is exerted on the tube to make it conform to the shape of the die cavity.

Table 1 : Properties of Aluminum alloy Tube Al6061T4

Density (kg/m^3)	2700
Melting point (°C)	643-657.2
Elastic modulus (GPa)	70
Yield strength (MPa)	35
Ultimate tensile strength (MPa)	89.6
% elongation	35
Hardness (HB)	23
Thermal conductivity (W/m-K)	222
Poisson’s ratio	0.3

COMPUTATIONAL PROCEDURES

- Material Property: the material is of alloy of aluminium Al6061T4. E= 70 GPaPoisson's ratio is 0.33. Yield stress is taken as 35 MPa for 20% strain.
- Tube Size: Outer diameter 11mm, length 200mm and wall thickness 2.5mm
- Process Parameter: Pressed shell with the help of different liquid pressure ranging from 1MPa to 10 MPa.
- Die Parameter: Die is made up of die steel AISI D6 having high compressive and wear resistance and good hardening stability.
- Friction Parameter: high friction coefficient show error on simulation model and aborted when reach aboveμ = 0.01. The three-friction coefficient taken as 0.005, 0.001 and 0.01.
- Time: The process completion time is 10 seconds.

Initially, the tube bending simulation was carried out using DEFORM-3D. Solid model of the tube was created as Deform-3D doesn't support shell modeling. The tube was meshed with tetrahedral mesh as shellmesh was not available in the software. The larger the number of mesh elements, the more accurate is the solution but the time consumed in solving is also more. In the case of a large work piece, a lot of mesh elements are needed in order to obtain the correct results. But this significantly increases the solving time. In our case, the tube length required was long so a large number of mesh elements were needed to maintain the accuracy of the tube. 400000 elements were used and still, the mesh volume was significantly different from the tube volume. With these many elements, the simulation took a very long time of close to a month to solve the problem and the results obtained were undesirable. So, further simulations were carried out on Abaqus FEA which also is software for finite element analysis. The use of Abaqus simplified the problem a lot as Abaqus allows the use of shell modeling instead of solid modeling and shell element mesh in place of tetrahedral mesh. Hence, the tube was modeled as a shell having shell type of mesh having 2704 mesh elements. The simplified problem reduced the solving time tremendously to a few hours and therefore the tube bending simulations were carried out on Abaqus. The shape of the die cavity is shown in Figure 2.

The initial shape of the tube and its initial position inside the die cavity are shown in Figure 3. The tube is closed at one end, its outer diameter is 11mm and a thickness of 2.5mm is assigned to it.

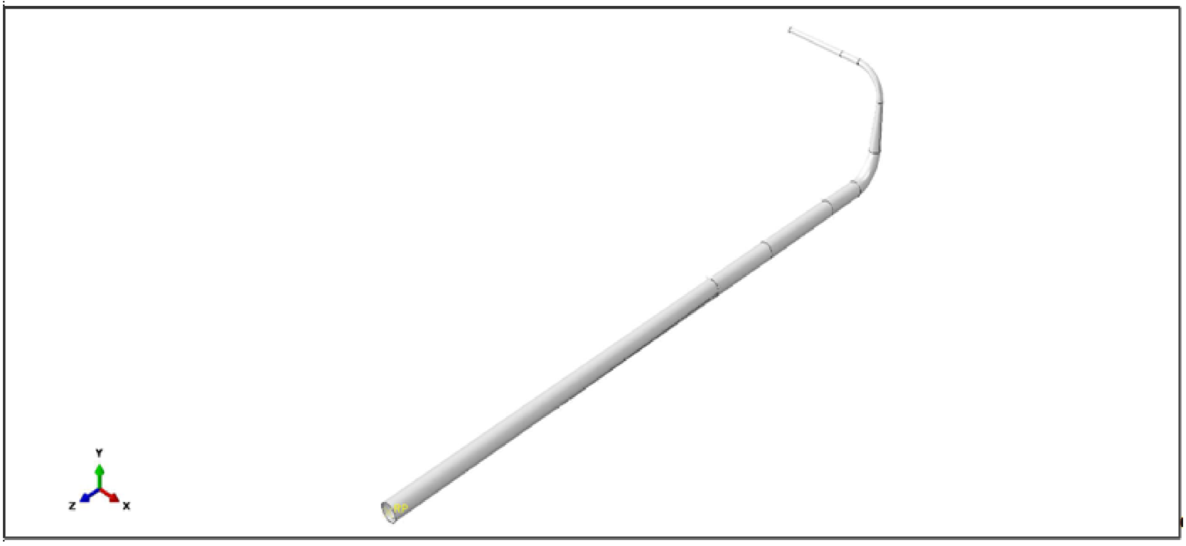


Figure 2 : Shape of die cavity

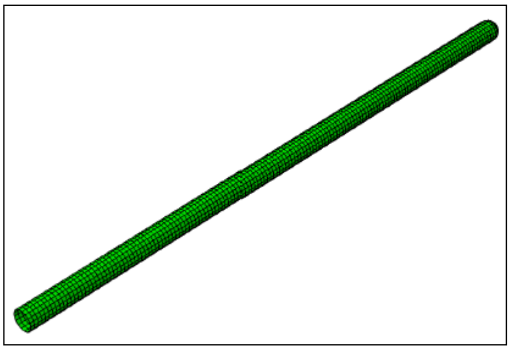


Figure 3: (a) Initial Tube Shape

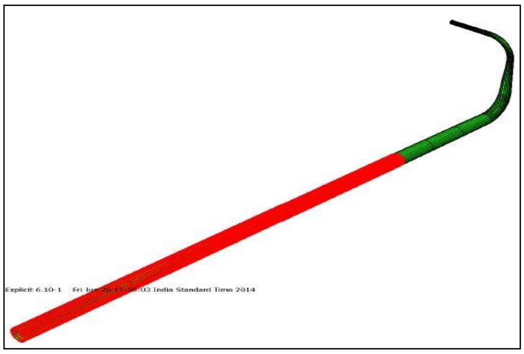


Figure 3: (b) Tube Placement in Die Cavity

Many simulations were carried out at different coefficients of friction and different internal pressures. As soon as the internal pressure was increased above 10MPa, the simulation got aborted and showed error. Similarly, when the friction coefficient was increased to 0.05 and above, the simulation did not get completed and showed error. Hence, it was observed that the process required low pressure and very low friction for completion.

RESULTS & DISCUSSIONS

The results shown are for coefficients of friction 0.01, 0.005, 0.001 and internal pressures 0.5MPa, 1MPa, 3MPa, 5MPa and 10MPa. The following figures show the thickness distribution in the formed tubes for these cases. a) μ= 0.01 b) μ= 0.005 c) μ=0.001

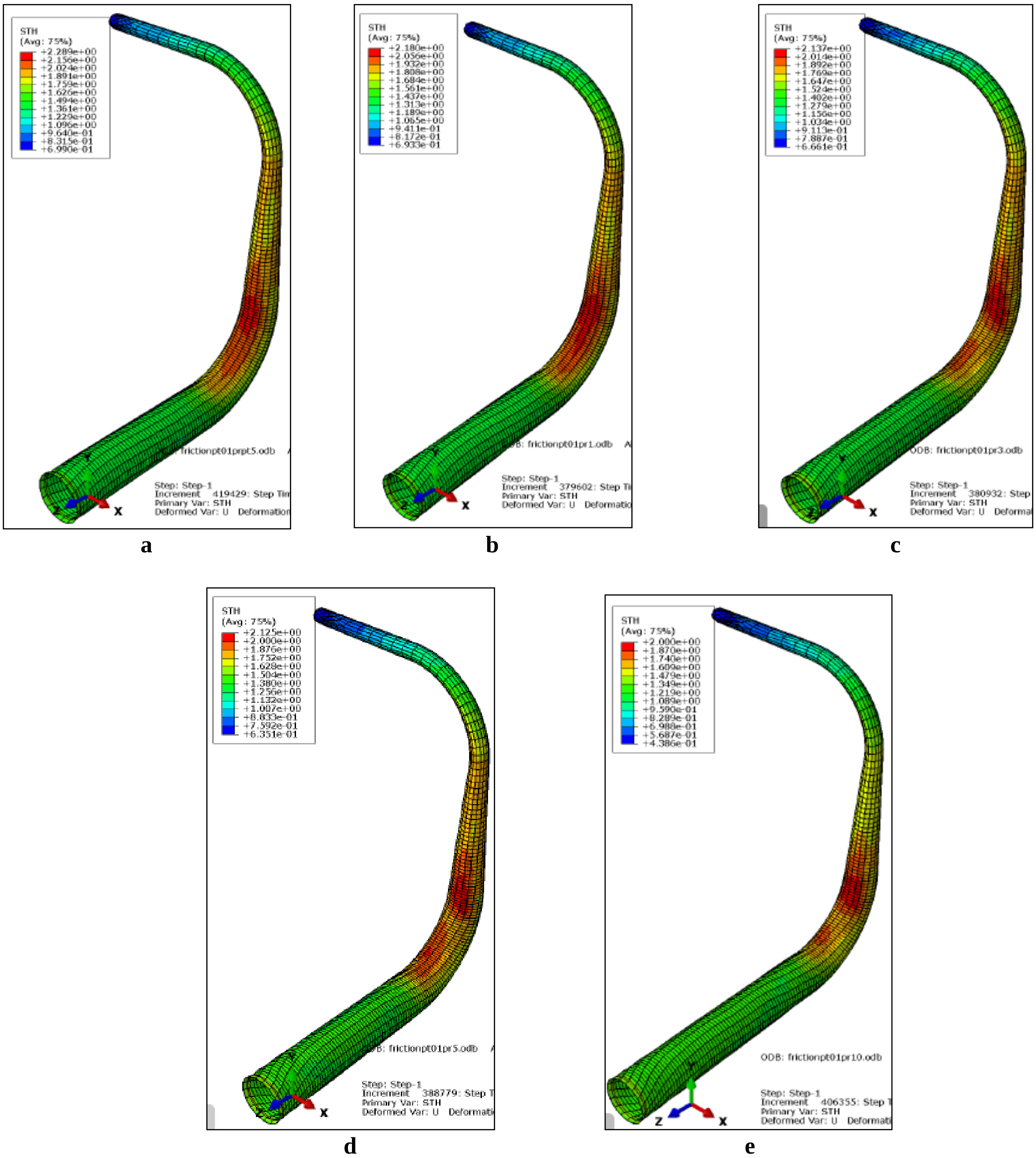
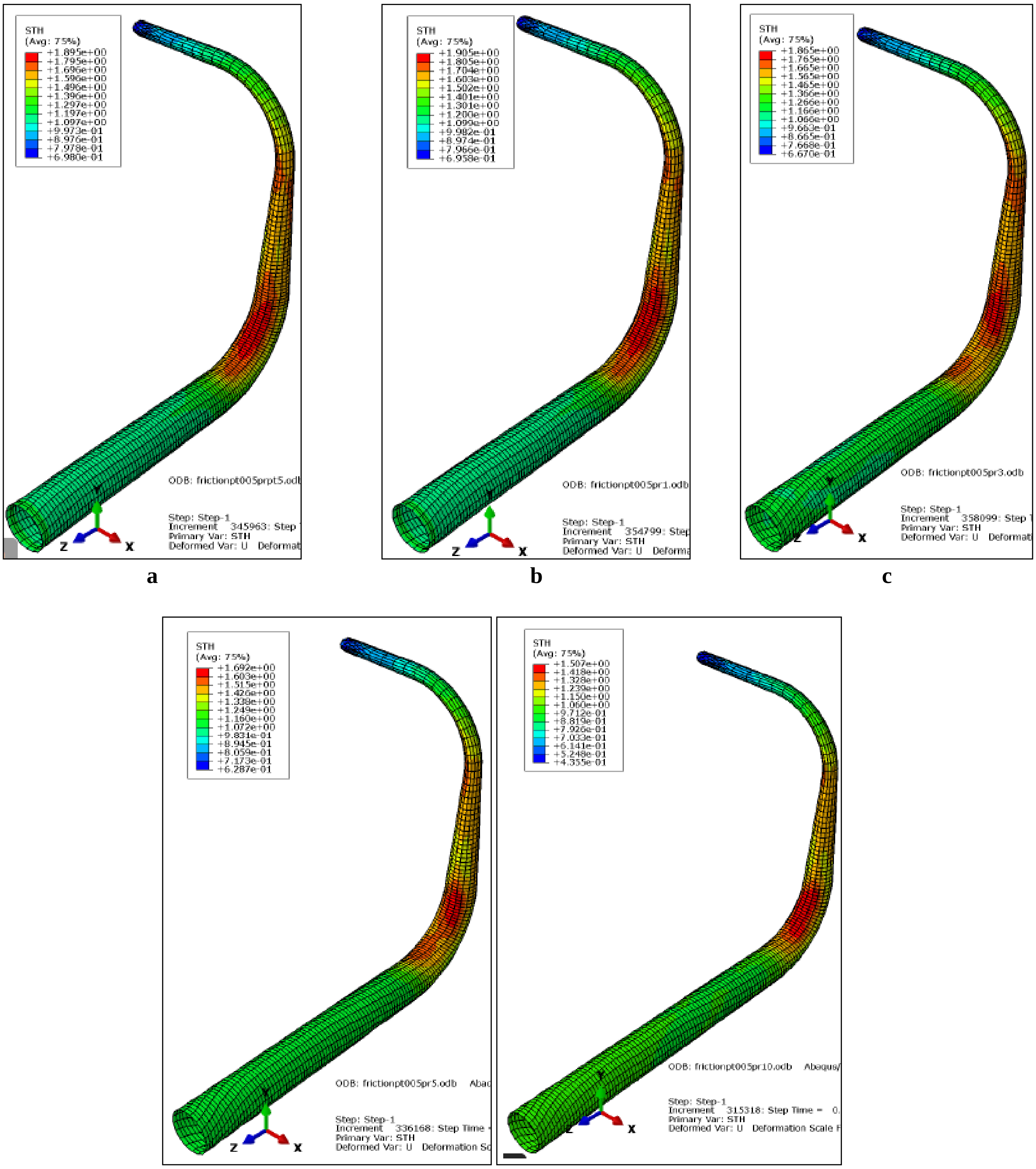


Figure 4 : Thickness distribution in the formed tubes at μ=0.01 and internal pressure (a) 0.5MPa (b) 1MPa (c) 3MPa (4) 5MPa (5) 10MPa



a **b** **c** **d** **e**

Figure 5 :Thickness Distribution In The Formed Tubes at μ= 0.005 and Internal Pressure (a) 0.5MPa (b) 1MPa (c) 3MPa (d) 5MPa (e) 10MPa

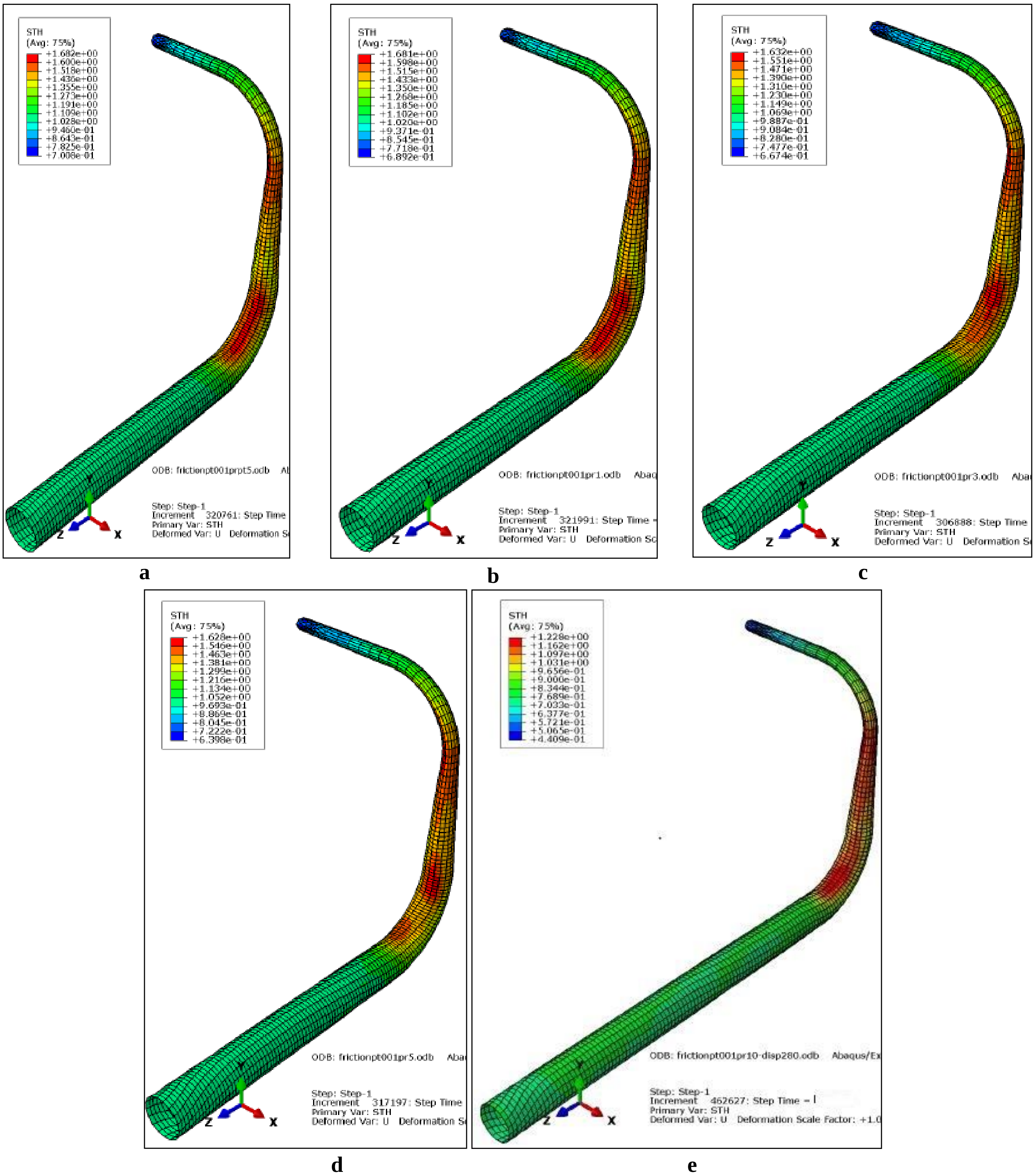
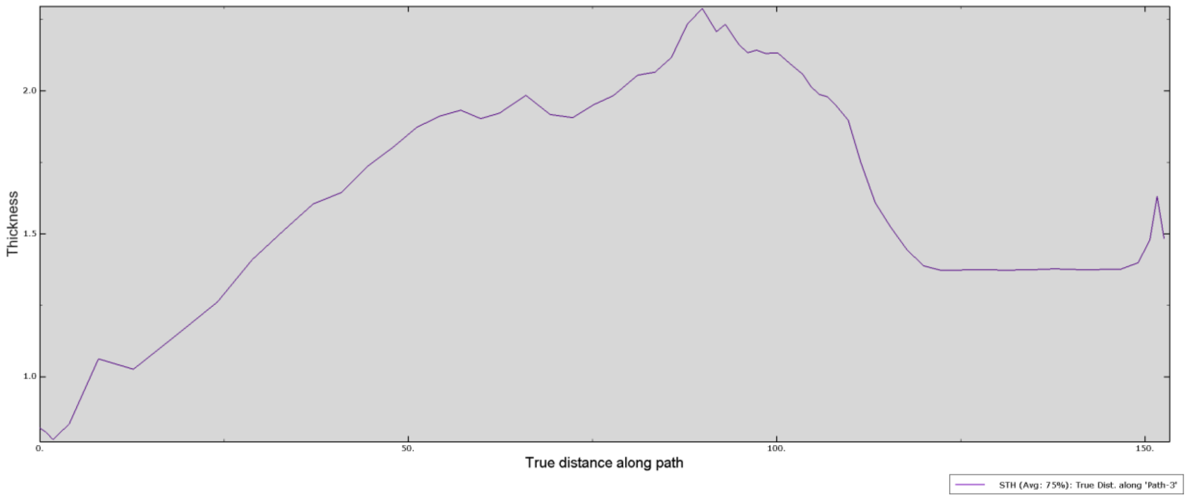


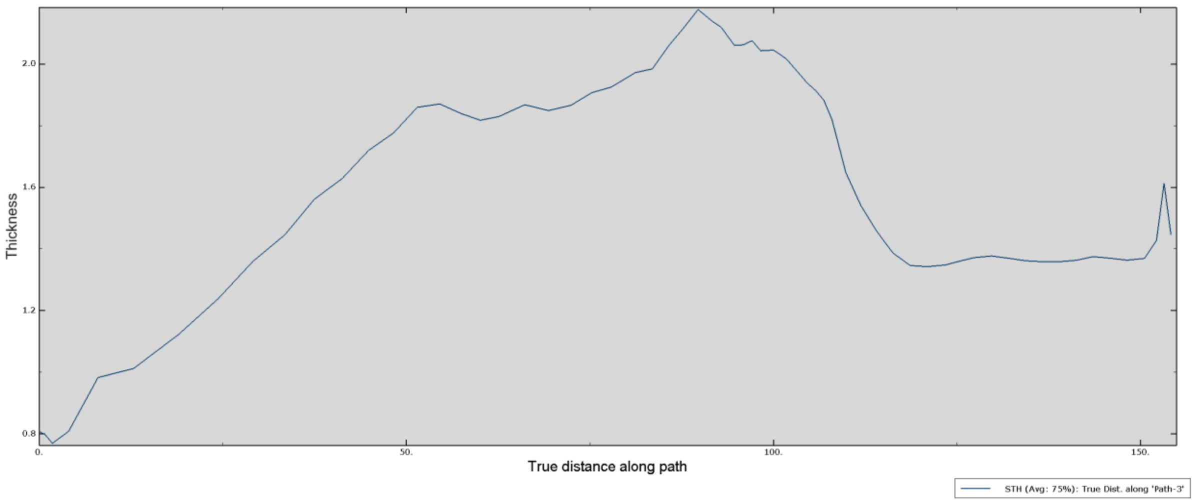
Figure 6 : Thickness Distribution in the Formed Tubes at μ= 0.001 and internal pressure (a) 0.5MPa (b) 1MPa (c) 3MPa (d) 5MPa (e) 10MPa

The following figures show the graphs of variation in tube thickness along the length of the tube for the cases studied. Thickness variation has been plotted starting from the closed end of the tube to the open end.

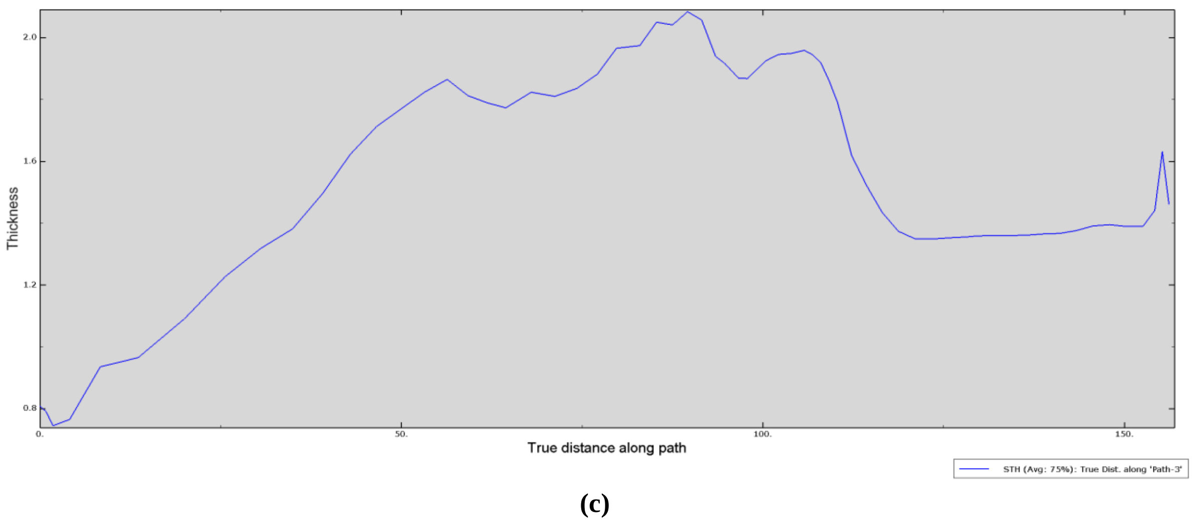
(a) μ= 0.01


Thickness
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

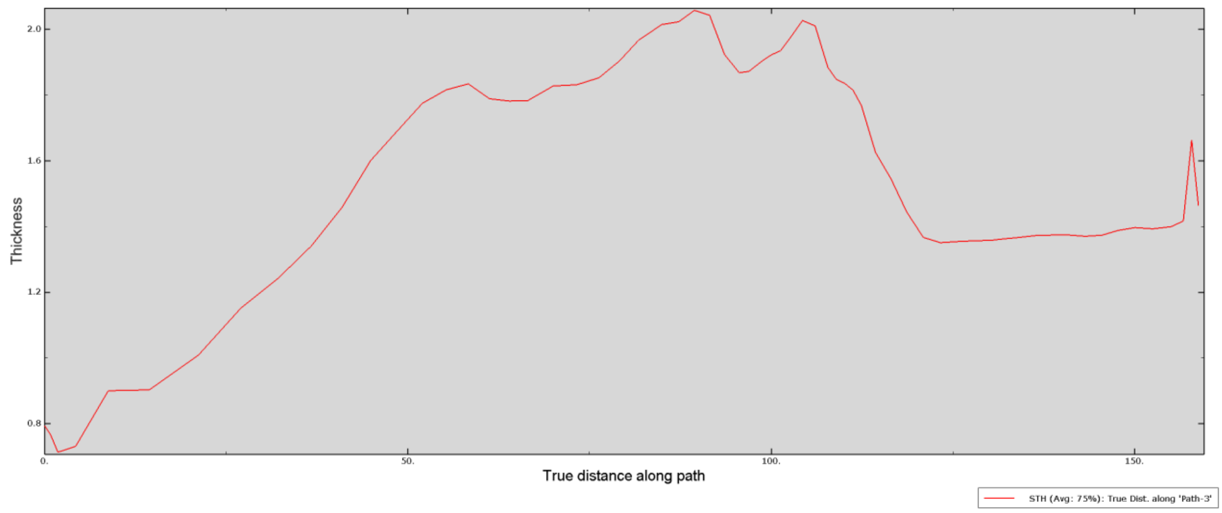
(a)


Thickness
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

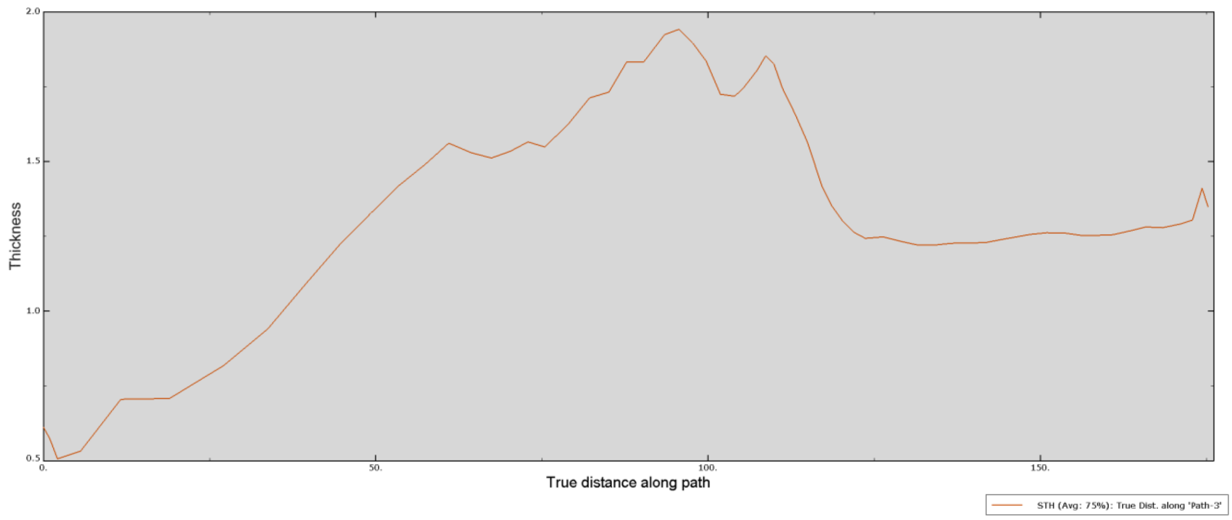
(b)


Thickness
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

(c)



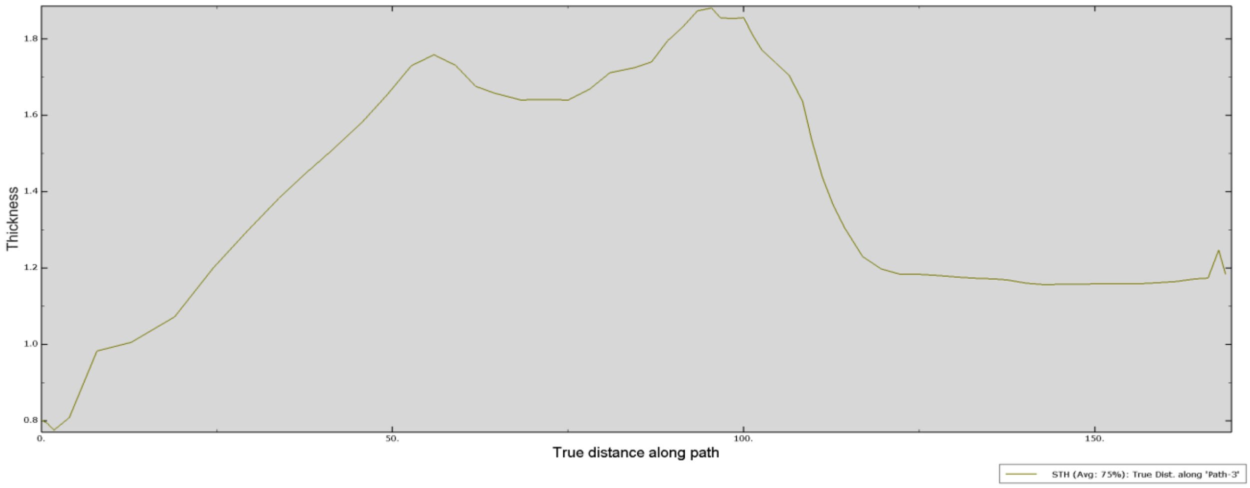
(d)



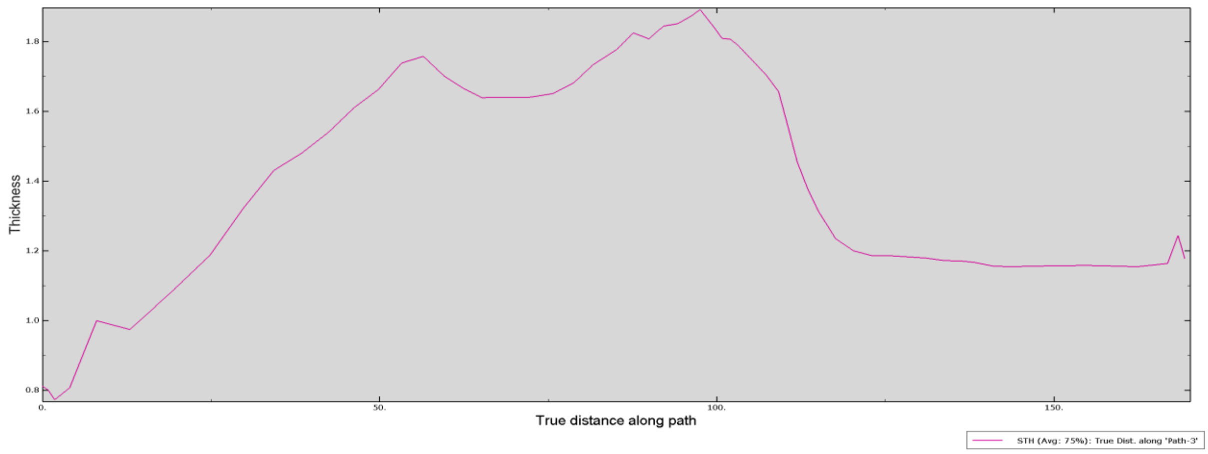
(e)

Figure 7 : Variation of Thicknessalong the Length of the Formed Tube With μ=0.01 And Internal Pressure (a) 0.5MPa (b) 1MPa (c) 3MPa (d) 5MPa (e) 10MPa

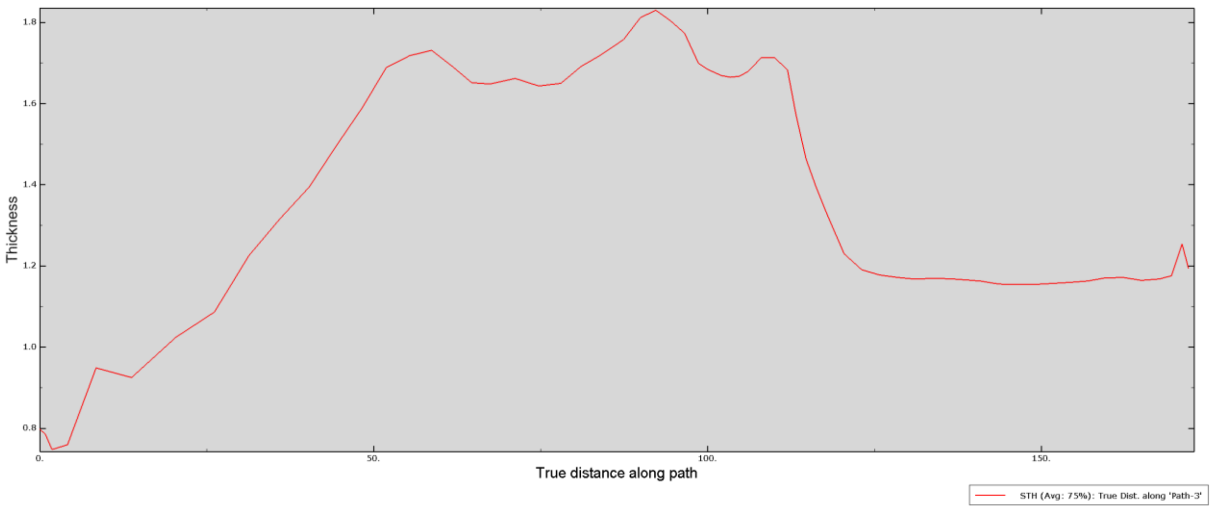
(b) μ= 0.005


Thickness
1.8
1.6
1.4
1.2
1.0
0.8
0.
50.
100.
150.
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

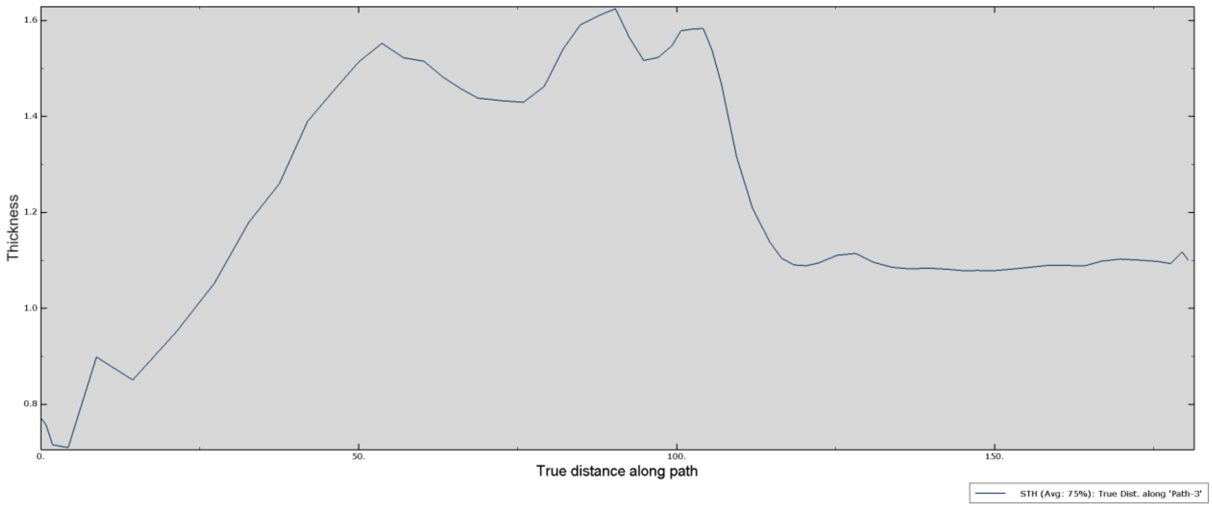
(a)


Thickness
1.8
1.6
1.4
1.2
1.0
0.8
0.
50.
100.
150.
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

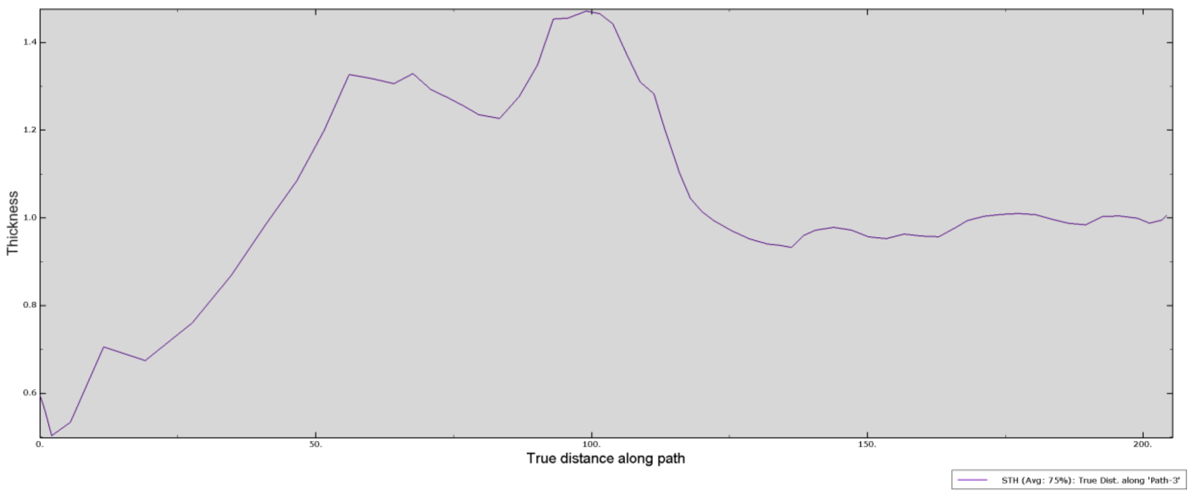
(b)


Thickness
1.8
1.6
1.4
1.2
1.0
0.8
0.
50.
100.
150.
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

(c)



(d)



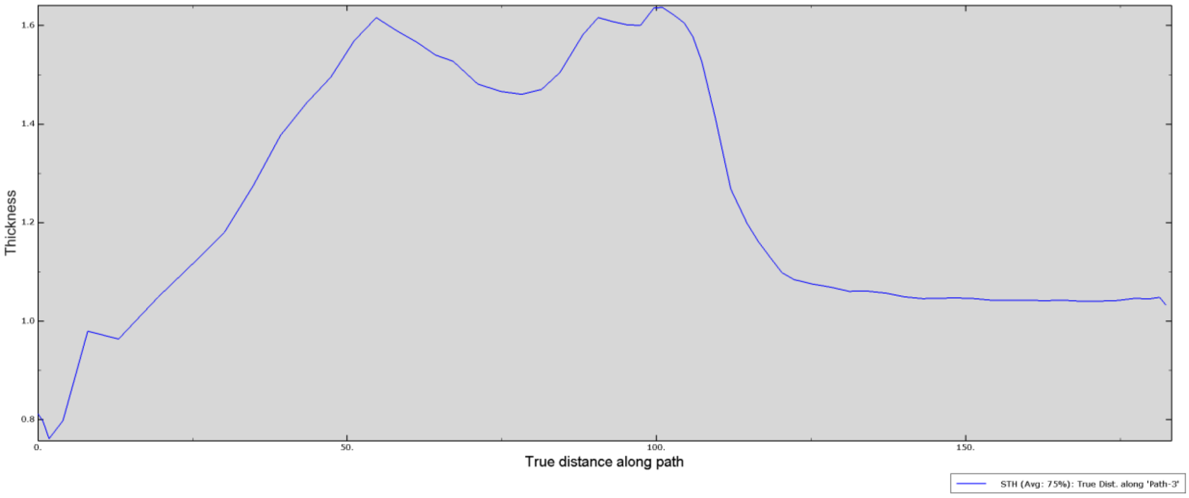
(e)

Figure 8 : Variation of Thickness along the Length of the Formed Tube with μ=0.005 and Internal pressure (a) 0.5MPa (b) 1MPa (c) 3MPa (d) 5MPa (e) 10MPa

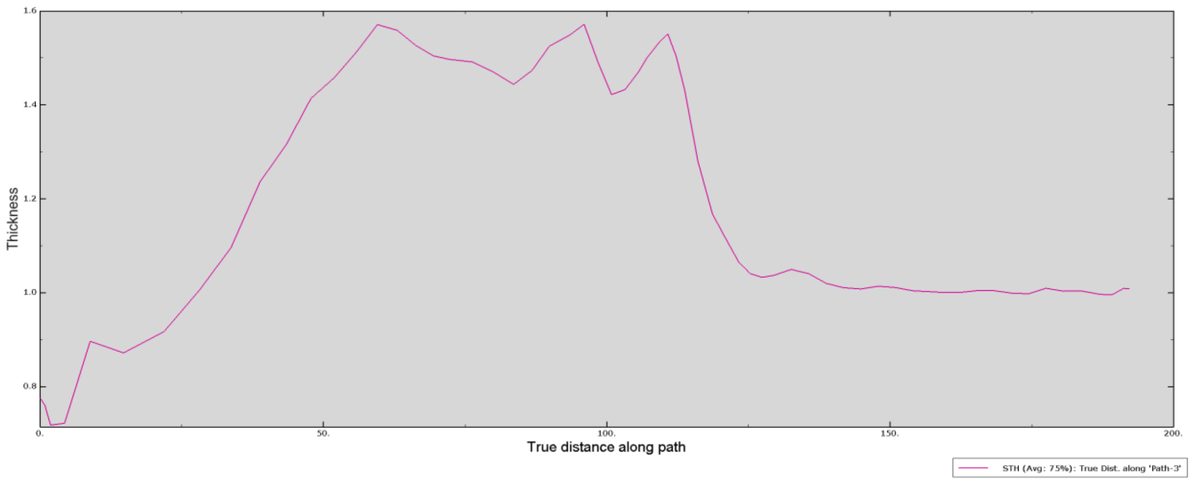
c) μ= 0.001


Thickness
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

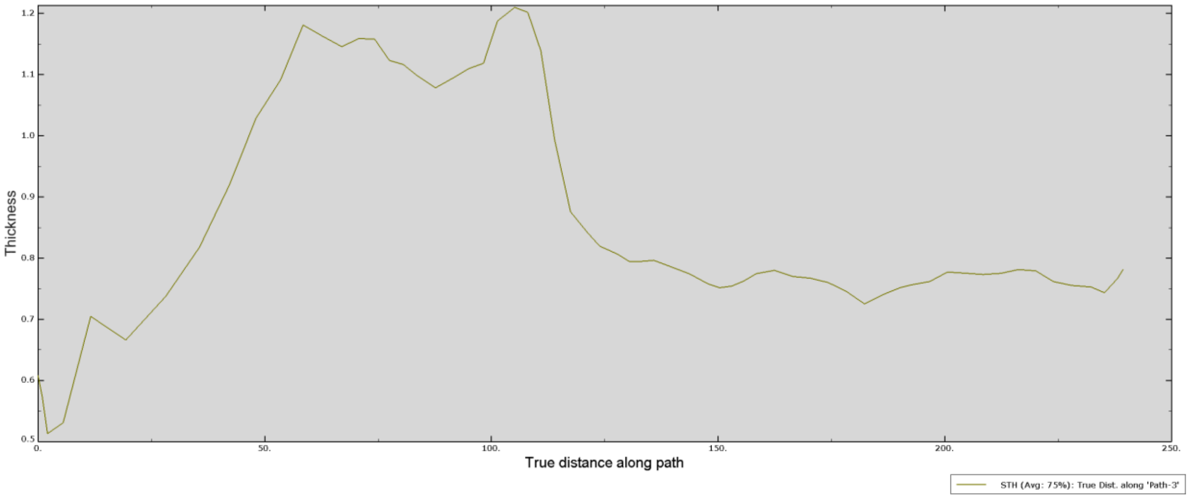
(a)


Thickness
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

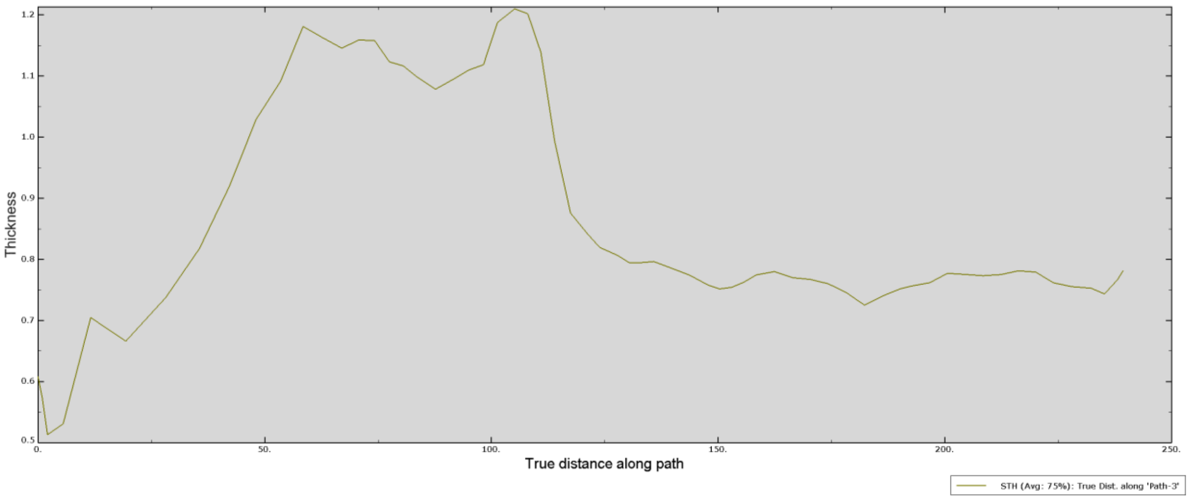
(b)


Thickness
True distance along path
STH (Avg: 75%): True Dist. along 'Path-3'

(c)



(d)



(e)

Figure 9 : Variation of Thickness along the Length of the Formed Tube With μ=0.001 and Internal pressure (a) 0.5MPa (b) 1MPa (c) 3MPa (d) 5MPa (e) 10MPa

CONCLUSIONS

- From the simulations carried out on tube bending, it was observed that the tube bending process required low friction coefficient and low pressure for forming.
- Simulations carried out at friction coefficient of 0.05 and above resulted in the abortion of simulations with errors of excessive rotation and distortion of nodes. Similarly, internal pressures above 10MPa also resulted in the abortion of simulations with the same errors.
- Hence, further simulations were carried out at friction coefficients of 0.01, 0.005 and 0.001 and internal pressures of 0.5MPa, 1MPa, 3MPa, 5MPa and 10MPa. In the case of simulations with high friction coefficients, there occurred high thinning of the tube. At lower coefficients of friction, the thinning of the tube was found to be lesser. This is because, at high coefficients of friction, flow-ability of the metal is poor due to high frictional

resistance forces.

- The highest thickening occurred at the region around the first bend in the case of simulations with the high friction coefficient and the thinning values in this region ranged from about 2 to 2.3mm based on the internal pressure. At lower coefficients of friction, the thinning around the regions of the first and second bends was found to be almost similar and the thinning values in these regions varied from around 1.2 to 1.6mm depending on the internal pressure.
- The best results were obtained at the coefficient of friction of 0.001. The thickening of the tube at the inner bend radius was found to be higher than that at the outer bend radius. This is because a higher bend radius results in a better flow ability of metal. At low pressures, the thickening was found to be higher and at higher pressures, the thickening was reduced. Best results were obtained at the pressure of 10MPa as still higher pressure resulted in excessive distortion and rotation of the nodes.

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